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Casing conveyed flowports for boreholes

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WO93/06336 A1
WO93/06333 A1
US5056595 A
US4790385 A
US4616701 A
US4541486 A
US3468386 A
US3385364 A
US3318381 A

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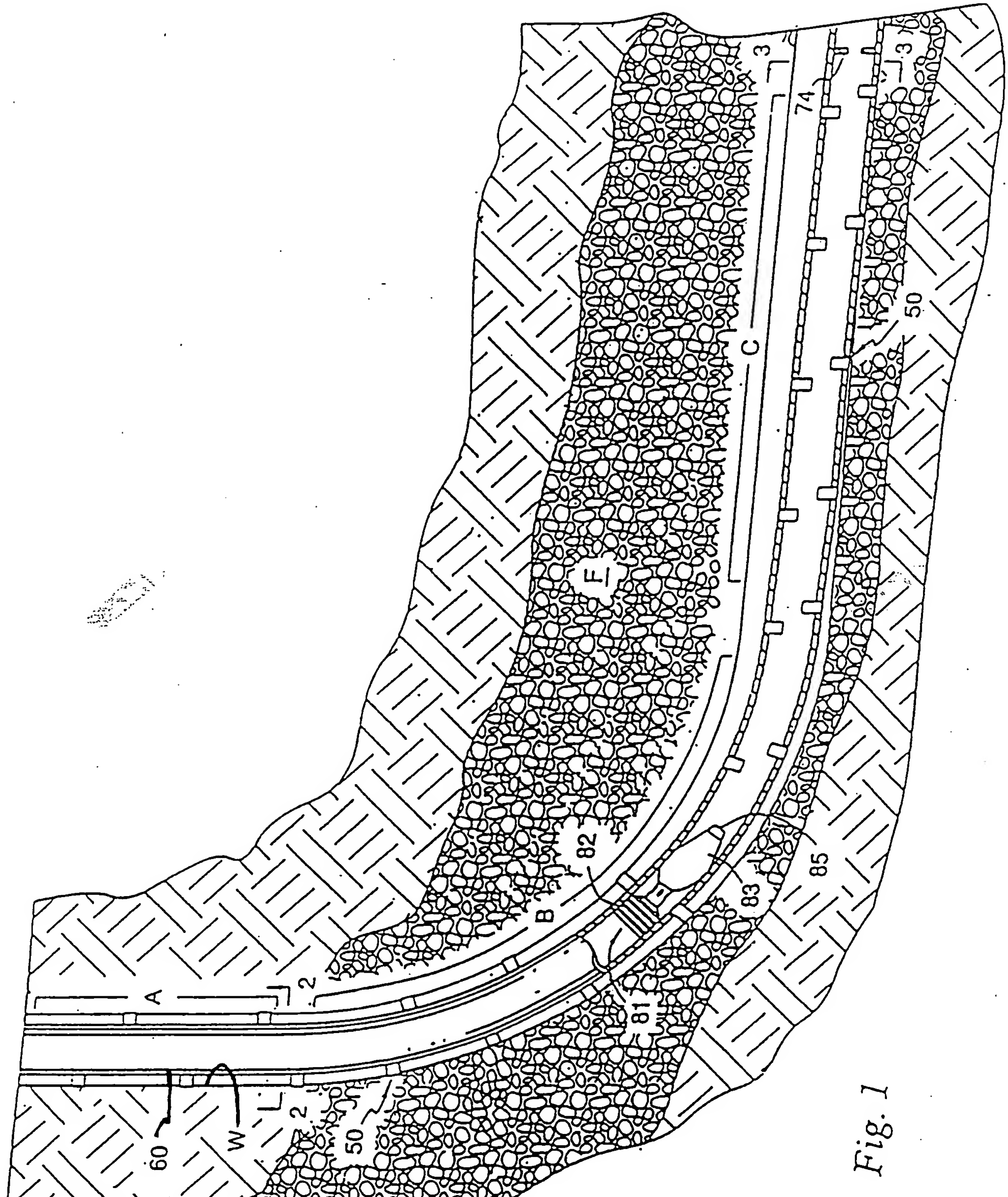

Fig. 1

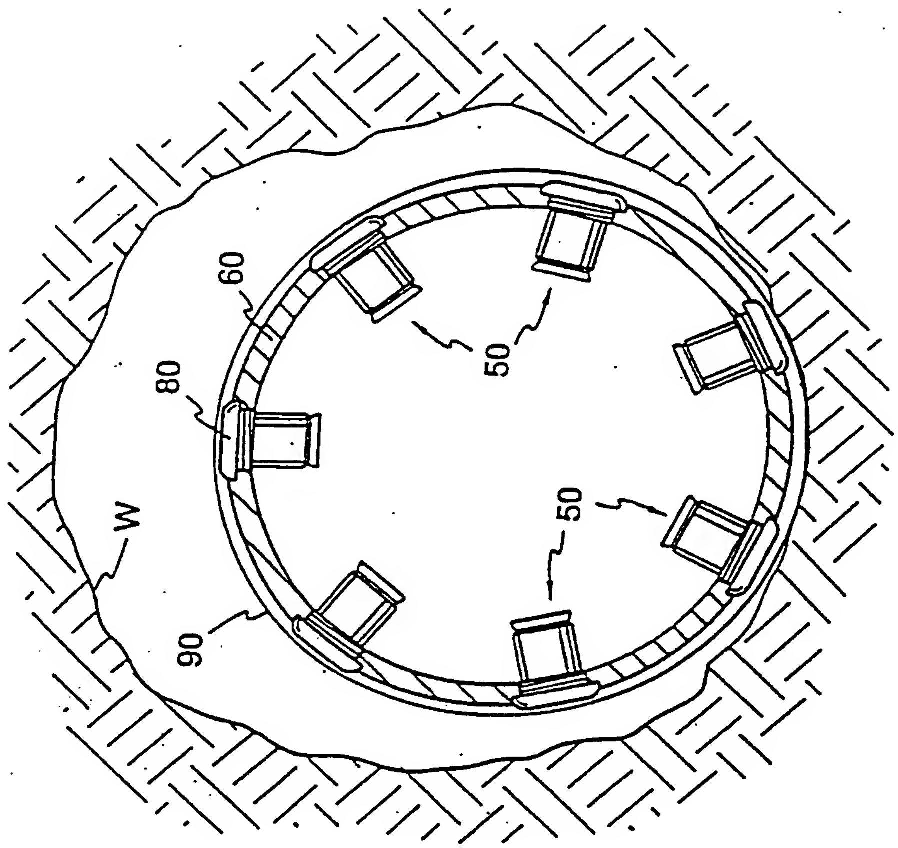

Fig. 3

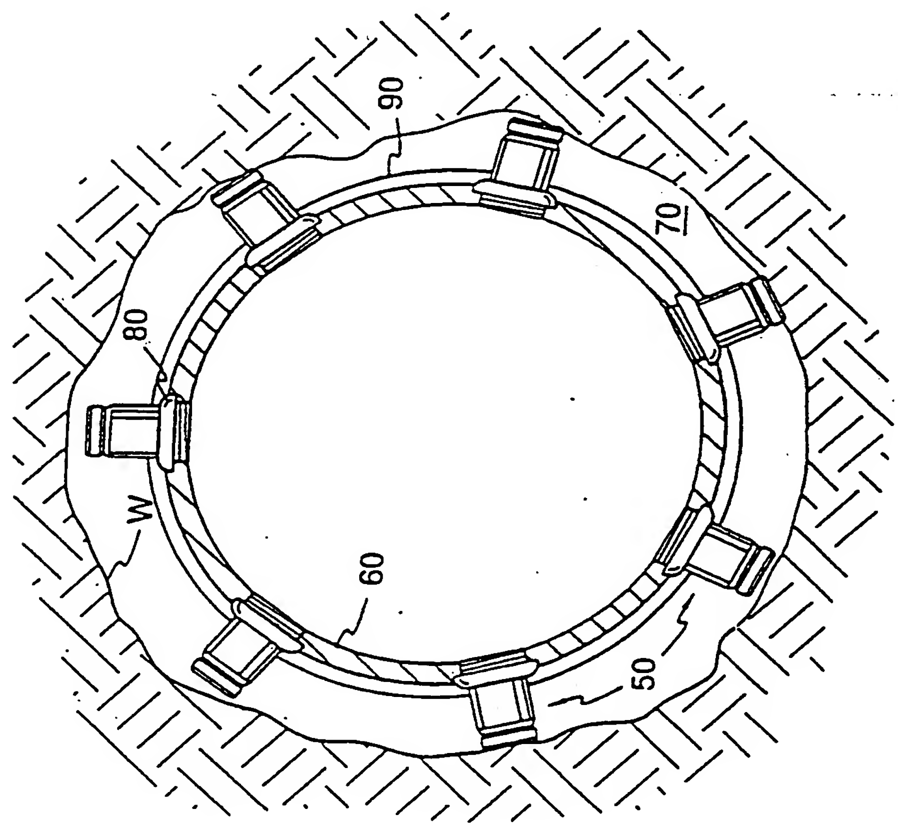

Fig. 2

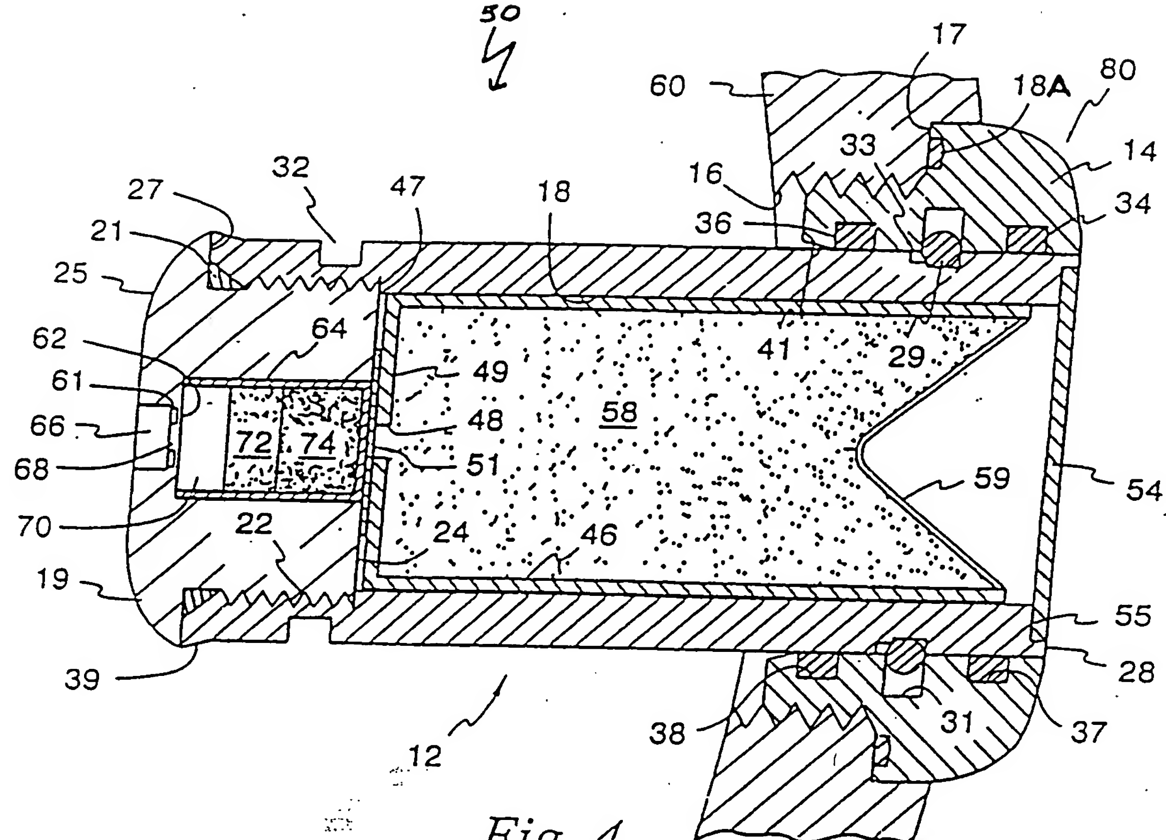
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Fig. 4

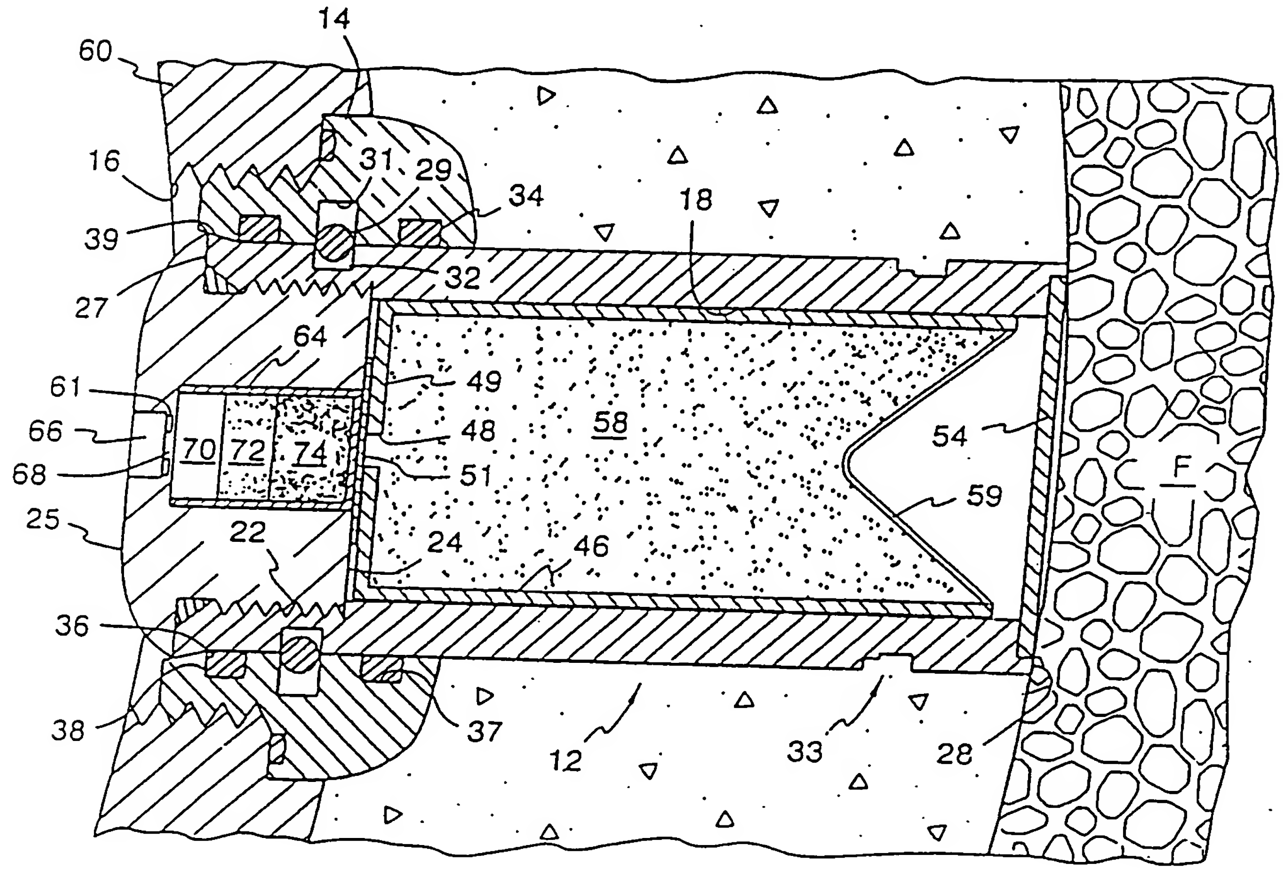
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Fig. 5

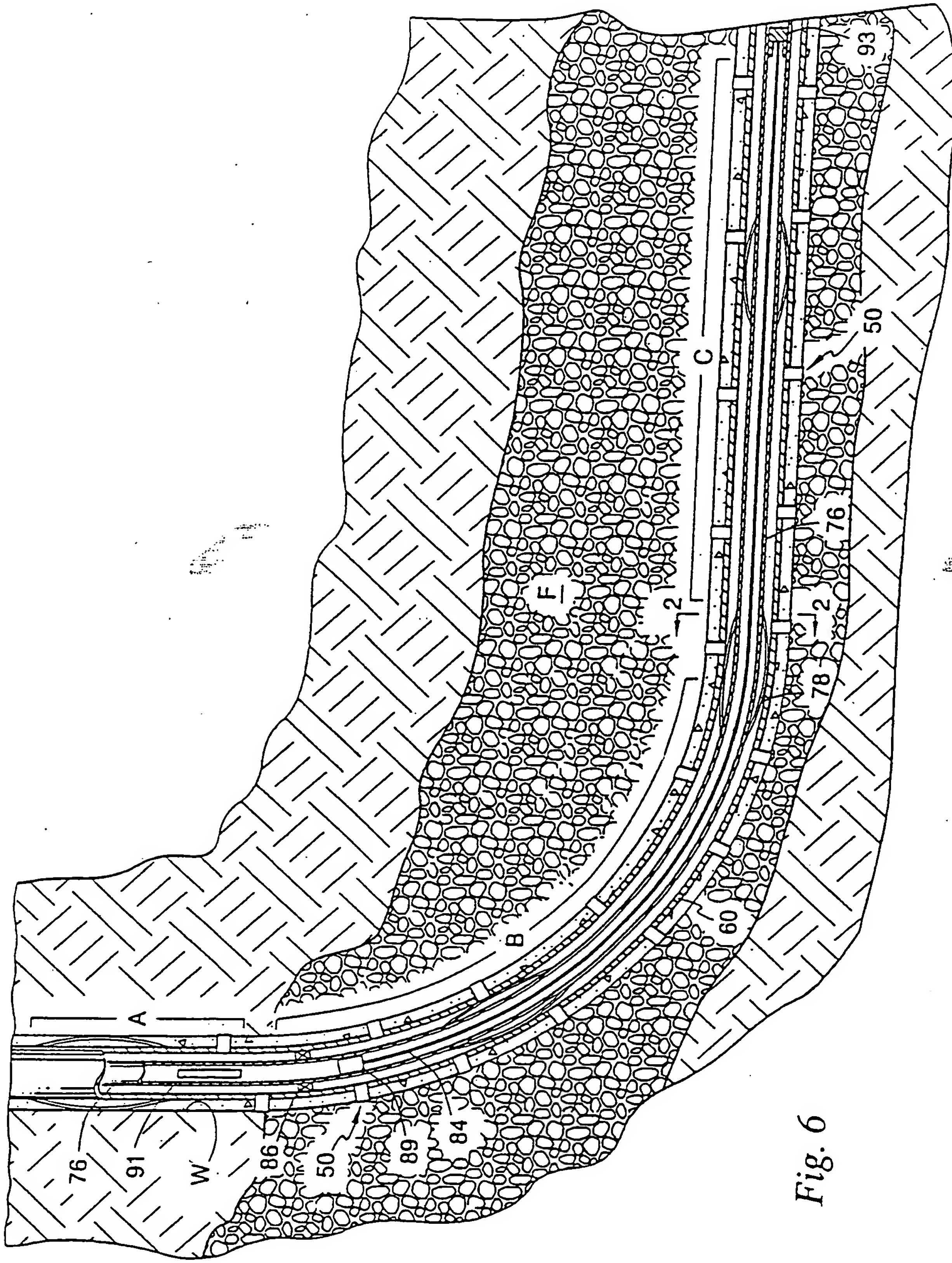

Fig. 6

224+10+

CASING CONVEYED FLOWPORTS FOR BOREHOLE USE

Field of the Invention

This invention relates to casing conveyed flowports and more particularly to an explosive device for opening flowports which are mounted in the wall of casing pipe or liners.

Background of the Invention

In the process of establishing an oil or gas well, the well is typically provided with an arrangement for selectively excluding fluid communication with certain zones in the formation to avoid communication with undesirable fluids. A typical method of controlling the zones with which the well is in fluid communication is by running well casing down into the well and then sealing the annulus between the exterior of the casing and the walls of the wellbore with cement. Thereafter, the well casing and cement may be perforated at preselected locations by a perforating device or the like to establish a plurality of fluid flow paths between the pipe and the product bearing zones in the formation. Unfortunately, the process of perforating through the casing and then through the layer of cement dissipates a substantial portion of the energy from the perforating device and the formation receives only a minor portion of the perforating energy.

Perforating in wellbores is typically accomplished by the use of perforating guns which usually employ shaped charges or bullets. The guns are usually positioned in the wellbore on a tubing string or suspended from a cable. Detonating the explosive in the gun is sometimes accomplished by initiating a detonating cord which is positioned in contact with a shaped charge.

Various electrical, hydraulic and mechanical systems are employed to initiate the detonating cord. The detonating systems which are now used in this industry have many safety drawbacks especially when electrical energy is used to initiate the explosives. The cost of performing the perforating operation when completing a well is very high especially on offshore completions where rig costs are excessive. Conventional perforating also causes damage to the formation due to glazing and vaporized material being forced into the rock.

Other completion techniques that are used to produce formations typically involve fluid treatment such as fracturing wherein a propant material is pumped into a casing pipe and then is forced through perforations in the pipe into fissures in the formation to open up the fissures which are already present in the formation. These fluid treatment techniques sometimes employ the use of perf balls or ball sealers that are pumped with the treating fluid into the pipe string. When an individual perforation begins to take a large amount of fluid, one of the ball sealers will migrate to that perforation and plug it so that the treating fluid is directed to another perforation. U.S. Patent 5,253,709 which is incorporated herein by reference discusses these treatments. A problem associated with using ball sealers is that perforation in pipe made by a shaped charge or bullet is often jagged and irregular and is difficult to seal with a ball.

As an alternative to perforating casing pipe, various arrangements of flowpath systems have been proposed. Tubular devices for establishing flowpaths between a casing string and formations traversed by a borehole were the subject of work done by Zandermer as set forth in U.S. Patents 3,358,770, 2,775,304, 3,347,317, 2,707,997, 3,326,291 as well as other patents such as

Prenner, et al, U.S. Patent 3,924,677. These systems utilize telescoping pistons or the like which are opened by chemical processes, hydraulic pressure or drilling. The unreliability or inconvenience of these systems as well as other disadvantages has prevented commercial acceptance by the industry.

It is therefore an object of the present invention to provide a new and improved completion technique that avoids the drawbacks associated with perforating a casing pipe.

It is a further object to provide a system to safely initiate an explosive device at a remote location in a casing pipe in order to open flowports extending between the pipe and formations traversed by a borehole.

Additionally, it is an object of the present invention to provide a method and apparatus for providing flowports in a wellbore which overcomes or avoids the above noted limitations and disadvantages of the prior art.

The above and other objects and advantages of the present invention have been achieved in the embodiments illustrated herein by the provision of an apparatus and method for initiating an explosive charge to open flowports between a casing pipe and earth formation. The explosive charge is initiated by means of a pressure pulse or shock wave. A pressure pulse generating device is positioned in proximity to but spaced from the explosive charge in order to open the flowports.

Additionally, the flowports and charges may be placed in the walls of the casing string in a wellbore and a pressure pulse generating device is run into the casing string in a separate operation.

In one embodiment, an explosive detonator is arranged in a housing having a rupture means in communication with a fluid environment so that when the rupture means is subjected to a sufficient pressure and ruptures, a detonator is subjected to a sudden pressure wave which initiates the detonator. Firing the detonator generates a force that opens a flowport.

In another embodiment, the system comprises an explosive device mounted in an opening in the peripheral wall of a pipe. An initiation device is then separately positioned in the wellbore for detonating the explosive device.

In another embodiment, the system utilizes an improved detonator device adapted for detonation by a predetermined pressure generated from a remote source when the detonator is in contact with a fluid environment. The detonator device is mounted in a housing which contains a base charge of a detonating explosive and a priming charge of a heat sensitive explosive adjacent to the base charge. The housing adjacent the priming charge is sealed from the fluid environment by a rupturable membrane or rupturable disc. Optionally, the detonator may include an open volume between the priming charge and the rupturable disc. This housing also comprises a flowport when opened. Generation of a pressure pulse from any convenient pulse generator, such as, for example, a detonating cord, at any remote location within the fluid and the subsequent sudden impact of the pulse on the rupturable disc reliably initiates the priming charge. This charge or a secondary charge is arranged in the housing to open a channel through the housing between the casing pipe and surrounding formations.

Brief Description of the Drawings

Figure 1 is a cross-sectional view of a wellbore traversing earth formations with a casing string arranged therein and spaced from the walls of the wellbore by a plurality of downhole activated pistons which are shown being activated to an extended position and which embody features of the present invention.

Figure 2 is an enlarged cross-sectional end view of the casing taken along lines 2-2 in Figure 1, wherein the centralizers are shown extended to center the casing string in the wellbore.

Figure 3 is a cross-sectional end view similar to Figure 2 prior to the casing being centralized and with the downhole activated centralizers in the retracted position.

Figure 4 is an enlarged cross-sectional view of a flowport piston having a detonator device and a secondary charge positioned therein for opening a flowport through the piston, with the piston shown in a retracted or running-in position relative to the casing wall.

Figure 5 is an enlarged cross-sectional view of an alternative flowport piston in an extended position wherein the outer end of the piston is in contact with an earth formation.

Figure 6 is a cross-sectional view of a wellbore showing a casing centralized in a borehole by flowport pistons in an extended position and further showing a pressure pulse generating device positioned in the casing by means of a pipe string.

Detailed Description of the Preferred Embodiments

Referring first to Figure 1 of the drawings, a wellbore W is shown having been drilled into the earth formations such as for the exploration and production of oil and gas. The illustrated wellbore W includes a

generally vertical section A, a radial section B leading to a horizontal section C. The wellbore has penetrated several formations, one of which may be a hydrocarbon-bearing zone F. Moreover, the wellbore W was drilled to include a horizontal section C which has a long span of contact with the formation F of interest, which may be a hydrocarbon-bearing zone. With a long span of contact within a pay zone, it is likely that more of the hydrocarbon present will be produced. Unfortunately, there are adjacent zones which have fluids such as brine that may get into the production stream and thereafter have to be separated from the hydrocarbon fluids and disposed of at additional costs. Accordingly, fluid communication with such adjacent zones is preferably avoided.

To avoid such communication with nonproduct-bearing zones, wellbores are typically cased and cemented and thereafter perforated along the pay zones. However, in the highly deviated portions of a wellbore such as the radial section B and the horizontal section C of the wellbore, the casing tends to lay against the bottom wall of the wellbore, thereby preventing cement from encircling the casing and leaving a void for wellbore fluids such as brine to travel along the wellbore and enter the casing far from the formation from which it is produced. In the illustrated wellbore W, a casing string or liner 60 has been run therein which is spaced from the walls of the wellbore by a plurality of downhole activated pistons generally indicated by the number 50, which serve to centralize the casing. The downhole activated pistons or centralizers 50 are retracted into the casing 60 while it is being run into the wellbore as is illustrated by the centralizers 50 in Figure 1 which are ahead of an activator or pusher 82. Once the casing 60 is suitably positioned, the centralizers 50 are deployed to project outwardly from

the casing as illustrated behind the activator or in Figure 1. The centralizers 50 move the casing from the walls of the wellbore if the casing 60 is laying against the wall or if the casing is within a predetermined proximity to the wall of the wellbore W. This movement away from the walls of the wellbore will thereby establish an annular free space around the casing 60. The centralizers 50 maintain the spacing between the casing 60 and the walls of the wellbore W while cement is injected into the annular free space to set the casing 60. The pistons, however, are latched in an extended position and will thereby maintain the casing 60 centered even if the casing is not cemented.

The centralizers 50 are better illustrated in Figures 2 and 3 wherein they are shown in the extended and retracted positions, respectively. Referring specifically to Figure 2, seven centralizers 50 are illustrated for supporting the casing 60 away from the walls of the wellbore W although only four are actually shown contacting the walls of the wellbore W. It should be recognized and understood that the centralizers work in a cooperative effort to centralize the casing 60 in the wellbore W. The placement of the centralizers 50 in the casing 60 may be arranged in any of a great variety of arrangements. In particular, it is preferred that the centralizers 50 be arranged to project outwardly from all sides of the periphery of the casing 60 so that the casing 60 may be lifted away from the walls of the wellbore W no matter the rotational angle of the casing 60. It is also preferred that the centralizers 50 be regularly spaced along the casing 60 so that the entire length of the casing 60 is centralized. The distance between centralizers and their radial orientation on the casing will vary depending upon the circumstances of a particular completion. For example,

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it is conceivable that the centralizers may be provided only in one radial orientation, or only at the ends of a section of casing. In Applicants' copending U.S. patent US-5346016, incorporated herein by reference, various arrangements are shown for mounting centralizer pistons in the wall of a pipe string.

Referring again to Figures 2 and 3, the seven illustrated centralizers 50 are evenly spaced around the casing 60. As the casing is centralized, an annular space 70 is created around the casing within the wellbore. The casing 60 is run into the wellbore with the centralizers 50 retracted as illustrated in Figure 3 which allows substantial clearance around the casing 60 and permit the casing 60 to follow the bends and turns of the wellbore W. Such bends and turns particularly arise in a highly deviated or horizontal hole. With the centralizers 50 retracted, the casing 60 may be rotated and reciprocated to work it into a suitable position within the wellbore. Moreover, the slim dimension of the casing 60 with the centralizers 50 retracted (Figure 3) may allow it to be run into wellbores that have a narrow dimension or that have narrow fittings or other restrictions.

In Figures 2 and 3 and in subsequent figures as will be explained below, the centralizers 50 may present small bulbous portions 80 on the outside of the casing 60. It is preferable not to have any dimension projecting out from the casing to minimize drag and potential hangups while moving the string. The outward projection of the retracted centralizers 50 being within the maximum outer profile of the casing string 60 is believed to minimize any problems of running the casing.

Referring again to Figure 1, a deploying device or pusher 82 which moves from the top of the casing to its bottom end is shown positioned within the horizontal curved

section B of the casing string. The deploying device 82 is sized to push the pistons 50 from a retracted to an extended position. It is noted that the centralizers or pistons 50 behind or to the left of the pusher 82 are in an extended position having been engaged by the tapered nose portion 85 of the pusher. The tapered portion 85 engages the inner ends of the pistons and pushes them outwardly as the piston travels until the body portion 83 has passed the piston whereupon the piston will be fully extended and locked into an extended position as will be hereinafter described. The centralizers in front of the pusher 82 are still in a retracted position and consequently the horizontal portion C of the casing in front of the pusher is shown lying on the bottom side of the borehole. The upper vertical section A and radial section B are shown centered in that the pistons 50 have been deployed to an extended position. The activator device shown in Figure 1 is a pumpable activator or deploying device having a tail pipe 81 which extends rearwardly from the main body portion 83 and seals the rear end of the device to the inside of the casing so that the device may be pushed down through the casing 60 by the application of hydraulic pressure.

The centralizers or pistons may take many forms and shapes as is illustrated in Applicants' U.S. Patent No. 5,228,518, incorporated herein by reference. In the present application, the piston or centralizer 50 is shown in Figures 4 and 5 as including an explosive charge for opening a flowport through the piston 12 to communicate the casing 50 with formations in the borehole. Referring first to Figure 4, the centralizer 50 has a cylindrical or substantially cylindrical barrel portion or piston 12 which is slidably received in a bore in button 14. The button 14 is threadedly received within a tapped hole 16 which extends transversely through the wall of casing 60. A

bulbous or rounded outer portion 80 extends outwardly slightly beyond the outside wall of the casing 60 but only to provide an adequate seat for the button 14 in thin wall smaller diameter casing and is constructed so that the outer extension of the bulbous portion 80 does not exceed the maximum profile of the pipe string which would normally be represented by the outside diameter of collars 90 in the casing string. The button 14 has a shoulder 17 formed at the base of the bulbous outer portion 80 that provides a surface for seating within a mating recessed surface at the outer end of the threaded hole 16 in the casing wall. The shoulder 17 forms a surface on the button which fits against the mating surface at the outer end of hole 16. An O-ring 18A is arranged within a groove on the shoulder 17 to provide a seal between the shoulder 17 and a face at the end of hole 16. The button 14 is arranged so that its inner end does not extend into the interior of the casing 60. The piston 12 is arranged for axial movement through the button 14 from a retracted position (Figures 3 and 4) to an extended position (Figures 2 and 5). The piston 12 and the button 14 are mounted into casing 60 so that their axis are collinear and directed radially outwardly with respect to the axis of the casing 60. The piston 12 includes a plug 19 secured in an interior bore or passageway 18 in the piston by screw threads 22. An annular sealing ring 21 is positioned between the plug 19 and the inner end of piston 12. The piston 12 shown in Figures 4 and 5 also serves as the flowport and as a housing for an explosive device to open the flowport. The plug 19 is called an initiator plug in that it carries a device for initiating detonation of an explosive to open the piston. As will be hereinafter described the initiating explosive in plug 19 may be of sufficient size to provide a force to remove the plug 19

without need for another explosive charge. The plug 19 does not fill the entire passageway 18 but is rather approximately the thickness of the casing 60. The plug 19 further includes a rounded inner end face 25 and a flat distal end face 24. The rounded surface 25 on the inner end of plug 19 is provided for facilitating the use of a deploying device to push the centralizer 50 into an extended position.

The distal end 28 of the piston 12 may be chamfered or tapered inwardly to ease the installation of the piston 12 into the button 14. The piston 12 is mounted in a central bore in the button 14 which is preferably coaxial to the opening 16 in the casing 60 and is held in place by a snap ring 29. The snap ring 29 is located in a snap ring groove 31 milled in the wall of the interior bore of the button 14.

Piston 12 includes two radial piston grooves 32 and 33 formed in the exterior cylindrical surface of the piston 12. The first of the two piston grooves is a circumferential securing or locking groove 32 which is positioned adjacent the inner end 27 of piston 12 to be engaged by the snap ring 29 when the piston is fully extended. The second of the two grooves is a circumferential retaining groove 33 positioned adjacent the distal end 28 of the cylinder 12 to be engaged by the snap ring 29 when the piston is in the retracted or running position as shown in Figure 4. As the piston 12 is illustrated in Figure 5 in the extended position, the snap ring 29 is engaged in the radial locking groove 32.

The snap ring 29 is made of a strong resilient material arranged to expand into the snap ring groove 31 when forced outwardly and to collapse when unsupported into the grooves 32 and 33 when aligned therewith. The snap ring 29 is resilient as noted above so that it can be

deflected deep into the snap ring groove 31 to slide along the exterior of the piston 12 and allow the piston 12 to move from the retracted position to the extended position. The snap ring 29 must also be strong to prevent the piston 12 from moving unless a sufficient activation force is applied to the piston 12 to deflect the snap ring 29 out of the retaining groove 33 into the snap ring groove 31 to permit the piston 12 to move through the snap ring to the extended position. The piston grooves 32 and 33 have a shape that in conjunction with the snap ring 29 allows the piston 12 to move in one direction but not the other. In the direction in which the snap ring 29 allows movement, the snap ring 29 requires an activation or deploying force of a certain magnitude before it will permit the piston 12 to move. The magnitude of the activation or deploying force depends on the spring constant of the snap ring 29, the relevant frictional forces between the snap ring 29 and the piston 12, the shape of the piston groove, and other factors. A particular arrangement of snap ring and grooves is shown in greater detail in Applicants' copending U.S. Patent US-5346016, incorporated herein by reference.

Once the casing 60 is positioned in the wellbore for permanent installation, the pistons are deployed to the extended position. The deploying method provides a deploying force on the inner end of each piston to overcome the resistance of the snap ring in the retaining groove 33 and cause the snap ring 29 to ride up and out of the retaining groove 33 whereupon the snap ring 29 is pushed up into the snap ring groove 31 within the button 14. This allows the piston to move out into the annular space of the wellbore. Once the piston encounters the wellbore wall, it will then lift the casing off of the wellbore to centralize the casing until such time as the snap ring 29 aligns with

and expands into the locking groove 32. The pistons should be of such a length that the pistons can be fully deployed to the locking groove 32 while giving the maximum amount of centralization. Once the pistons are fully deployed, the inner surface 25 on the plug 19 will be substantially clear of the casing bore for all practical purposes, and the casing bore should be substantially full opened.

The button 14 further includes a sealing arrangement to provide a pressure tight seal between the piston 12 and the button 14. In particular, the button 14 includes two O-rings, 34 and 36, which are positioned on either side of the snap ring 29 in O-ring grooves 37 and 38, respectively. The O-rings 34 and 36 seal against the exterior of piston 12 to prevent fluids from passing from one side of the casing wall to the other through the bore of the button 14. The O-rings 34 and 36 must slide along the exterior of the piston 12 passing the piston grooves 32 and 33 while maintaining the pressure tight seal. Accordingly, it is a feature of the preferred embodiment that the spacing of the O-rings 34 and 36 is such that as the piston 12 moves through the bore of the button 14 from the retracted position to the extended position, one of the O-rings 34 or 36 is in sealing contact with a smooth exterior surface of the piston 12 while the other may be opposed to one of the piston grooves 32 and 33.

The piston 12 further includes an outwardly tapered enlarged diameter peripheral edge 39 on its inner end 27, which edge 39 is larger than the bore in button 14 that receives the piston 12. Thus the edge 39 serves as a stop against the button 14 to limit the outward movement of the piston 12. The inside face of button 14 includes a chamfered edge 41 for engaging the outwardly tapered peripheral edge 39 on the piston when the inner end 27 of the piston is approximately flush with the inner end face

of the button 14. Therefore, while the extended piston 12 is recessed into the button 14 and clear of the interior bore of the casing 60, the inwardly facing rounded surface 25 of the initiator plug extends slightly into the bore of the casing for purposes to be described so that it is substantially clear of the bore to render the casing bore fully open to permit passage of the deploying device 82 or other similar device such as packers or the like that would be passed through the bore of a casing string.

Still referring to Figure 4, the inner bore 18 of the piston 12 is shown having a canister insert 46 installed therein. The insert includes a cup-shaped canister or carrier 46 which is sized to be press fit into the bore 18 of the piston 12. A locking compound is used to hold the canister 46 in the bore cavity of the piston. The carrier 46 is nested against a shoulder 47 in the piston bore 18, the shoulder 47 being the end of the threads 22 which are cut in the bore 18 of the piston at its inner end to receive plug 19. An ignition hole 48 is formed in the inner wall 49 of the cup-shaped carrier 46. A thin metal foil 51 is placed over the outer surface of hole 48 facing the plug 19. A secondary charge 58 is positioned in the canister 46 and is arranged to provide an explosive force to act against the plug 19 and strip the threads 22 to move the plug into the casing bore. Wax 54 or the like is installed in the canister to hold the charge 58 in place and to keep debris and fluids from contacting the charge 58. The force from charge 58 and from charges in the detonator plug would also open the wall 49, foil 51, and to fully open a flowport through the bore 18 of the piston 12.

It is noted that the piston 12 may be arranged to omit the carrier 46 and foil 51 and thus to not be provided with a secondary charge 58 as shown in Figure 5. Such an

empty piston configuration will provide an alternative arrangement to open a flow path between the casing bore and the formation wall. The detonator charges 72, 74 in plug 19 would be used to selectively discharge or remove the plug 19 upon their activation which would provide such a flow path between the formation and casing. The cylinder 12 shown in Figure 5 has wax 54 installed in the bore 18 to protect the interior of the piston from encroaching debris and fluids as the casing string 60 is positioned in the borehole. This wax could also be loaded into a canister as shown in Figure 4. The plug 19 has a cylindrical recess 62 which is formed from the inner side of the plug 19 for receiving a detonator shell or casing 64. The shell 64 is held in place within the recess 62 by means of a thread locking compound or the like. On the rounded outer surface 25 of the plug 19 and central to the plug 19, a recess 66 is formed in the outer wall surface 25 opposite the recess 62 on the interior of the plug 19. The recess 66 may be for example 3/16 inch (0.48 cm) in diameter and approximately .040 inches (0.10 cm) deep to leave an integral rupture disc portion 68 formed between the recesses 62 and 66. The rupture disc 66 may be on the order of .0275 (0.07 cm) inches thick. The shell 64 which is assembled within the recess 62 has provided within its interior bore a detonating system which is comprised of an optional air space 70, a primary charge of lead azide 72, and a base charge of RDX explosive 74.

The space between the top surface of the priming charge 72 and the rupture disc 68 is optional and can be any distance from about zero up to whatever space is available in this application. Rupture disc 68 may be adapted by any suitable means known in the art to seal the end of the tubular shell 64. Typical base charges that can be used are pentaerythritol tetranitrate (PETN), cyclortrimethylene trinitramine (RDX), cyclotetramethylene

tetranitramine (HMX), picrylsulfone, nitromannite, trinitrotoluene (TNT), hexanitrostilbene (HNS), lead azide and the like. Covering the base charge is a priming charge 72 that can be flat as shown or tapered and embedded in the base charge. Typical priming charges are of lead azide, lead styphanate, diazodinitrophenol, mercury fulminate and nitromannite. Mixtures of diazodinitrophenol/potassium chlorate, nitromannite/diazodinitrophenol and lead azide/lead styphanate also can be used. A separate layer of lead styphanate or a layer of a mixture of lead styphanate can be placed over lead azide. The size of the charges 72, 74 can be adjusted upwardly until they ar sufficient to force the plug 19 to strip out of the threads 22 and eject into the casing bore or to simply enlarge the opening through the plug 19. The tubular shell 64 and the rupture disc 68 can be aluminum, magnesium, brass or any metal, plastic, or other suitable material.

In the detonator arrangement of Figures 4 and 5 the rupture disc includes a circular groove 61 formed inwardly into the plug 19 from the recess 66. This groove 61 can be formed on either or both sides of the rupture disc 68. In order to accommodate this groove 61, the rupture disc 68 is made thicker so as not to unnecessarily weaken the integrity of the barrier 68 that protects the detonator shell 64. By undercutting the circular groove or rim 61 around the circumference of the rupture disc 68, the disc 68 will yield more predictably than by relying solely on normal yield of the metal between the recesses 66 and 62. This in turn improves initiation reliability. Also, a thicker disc 68 can be provided between the recesses 66 and 62 to protect the detonator from inadvertent activation by movement of a piston activating or extending device 82 through the casing bore.

In Figure 5 of the drawings, the centralizing piston 12 is shown having been moved to an extended and locked position wherein the distal end 28 of the piston is in contact with the bore hole wall. A deploying device 82 such as is shown in Figure 1 has been moved through the interior bore of the casing string to contact the outer surface 25 of plug 19 on the inner end of the piston. As the deploying device 82 passes the position in the casing string where the cylinder is positioned, the cylinder is forced outwardly with sufficient force to override the restraining effect of the snap ring 29 in the retaining groove 33. This overriding force causes the snap ring to move upwardly and expand outwardly into the groove 31 as it expands over the outer surface of the piston 12. The piston continues its movement until the tapered enlarged portion 39 on piston 12 abuts the mating chamfered surface 41 on the button 14 whereupon the piston 12 is positioned so that the snap ring 29 retracts into the locking groove 32 to hold the extended cylinder 12 in a predetermined fixed position. At this point, the deploying device 82 (Figure 1) will have passed the extended piston 12 and proceeded downwardly through the casing string. Once the piston is extended and locked in its predetermined fixed position as shown in Figure 5, the perforating apparatus is now in a position to permit opening of a flowport into the formation which the wellbore traverses. It is noted, that alternatively the pistons 12 may be extended by the application of hydraulic pressure to the interior of the casing pipe string which provides a force that impinges on the inner end of the piston to move the pistons outwardly.

It is to be noted that one particular advantage of the apparatus described herein is that the centralizing piston and a button 14 which guides the piston, when provided, may be assembled within the casing string at some

time just before the casing is run into the wellbore W. Accordingly, the handling of the casing pipe up to the point that it is being installed in the wellbore is not subjected to the danger which might be caused by having the explosive devices installed during shipping and handling of the casing prior to its installation. It is also to be noted that there is no means present within the system thus far described to accidentally initiate the detonator device within the piston so that such handling in the configuration described above is considered safe and will not unnecessarily endanger the personnel who are installing the devices in the casing or installing the casing within the wellbore.

Referring now to Figure 6 of the drawings, the casing 60 is shown having been run into a well. The centralizers are shown having been extended by means of a pumpable activator device 82 such as shown in Figure 1 or by the application of hydraulic pressure to the casing string at the surface. This is accomplished by closing a valve at the base of the casing string and applying the necessary activation or deploying force required to move the pistons from the retracted position to the extended position. Accordingly, pumps or other pressure generating mechanism would provide the necessary deploying force for the pistons.

Once the casing has been centralized within the wellbore, an annulus of cement can be injected and set around the entire outer periphery of the casing, over some appropriate interval of casing, to seal the casing from the formation. As suggested by the present invention, the casing string with the centralizer system as described is arranged so that in those portions of the wellbore where it is desired to have a centralizing only function for the centralizers, the centralizers are not configured so as to

provide a perforating function. However, within a zone opposite formation F as shown in Figure 6, where it is desirable to open the casing to permit the recovery of fluids from the formation into the casing string and to perforate the formation, the centralizers are of the embodiment shown in Figures 4 and 5 which include an explosive charge for opening the flowports to the formation to be produced.

In the initial installation of the casing within the wellbore, it is important to note that the centralizers which are not extended permit the casing to be rotated and reciprocated to work past tight spots or other interferences in the hole. These retracted centralizers 50 also do not interfere with the fluid path through the casing string so that fluids may be circulated through the casing to clear cuttings from the end of the casing string. Also the casing interior can be provided with fluids that are less dense than the wellbore fluids, in the annular space, causing the casing string to float. Clearly, the flowport centralizers 50 of the present invention permit a variety of methods for installing the casing into its desired location in the wellbore.

Once the casing 60 is in a suitable position, the centralizers are deployed to centralize the casing. As discussed above, there are several methods of deploying the centralizers. Once the pistons are all deployed and the snap rings have secured them in the extended fixed position projecting outwardly toward the wall of the wellbore, the cement may be injected by well known techniques into the annulus formed by the centralizing of the casing within the borehole.

The cement around casing 60 may be allowed to set while the production string is assembled and installed into the casing. It is important to note that at this point in

the process of establishing the well, the casing and wellbore are sealed from the formation. Accordingly, there is as yet no problem with controlling the pressure of the formation or with loss of pressure control fluids into the formation. In a conventional completion process, the perforation string is assembled to create perforations in the casing adjacent to the hydrocarbon bearing zone. Accordingly, high density fluids are provided in the wellbore and the production string to maintain a sufficient pressure head against the affect of formation pressure to avoid a blowout situation. While the production string is assembled and run into the well some of the wellbore fluids, in an overbalance condition, may be forced into the formation. Accordingly, the production string must be installed quickly to begin producing the well once the well has been perforated. However, with the present invention, such problems are avoided. Once the casing is set in place, the production string may be assembled and installed in the casing before the casing is opened to the formation. If the production string is already in place in the well, adequate surface controls are already in place to prevent a blowout, so that the casing and production string can be in an underbalanced condition. Thus, production may begin when communication is established with the formation, such as by opening the flowports. Accordingly, the well is brought on-line in a more controlled manner.

Figure 6 shows an apparatus and system for initiating the detonators in shell 64 (Figure 5) in the pistons, in order to open the flowports to the formation. A small diameter pipe string such as production tubing 76 or coiled tubing is run into the interior of the casing string after the centralizers flowport 50 are extended. The casing may or may not be cemented in place. A detonating cord 84 may be pre-installed in the lower end of

the tubing string 76 and run into the well with the tubing string. Alternatively, the tubing string may be located in the casing string and then the detonating cord is run into the tubing string. In the latter case, in order to set the detonating cord 84 in place, the bottom of the tubing string could be provided with a latching mechanism 93. After the tubing 76 is run into the casing string, a sinker bar with detonating cord trailing behind, can be lowered into the tubing string and latched inside of the tubing. Alternatively, a device can be pumped to the latch 93 with a detonating cord trailing. A perforating head 89 would be run at the trailing, upper end of the detonating cord 84 to provide a means for initiating the detonating cord. Once the tubing is run, a production packer 86 can be set. At this time a sinker bar 91 can be dropped which would strik the perforating head and initiate the detonating cord. Alternatively, a wireline could be connected with the detonating cord or perforating head in order to initiate the detonating cord.

The detonating cord is initiated by dropping a latch bar 91 or using a wireline to initiate a perforating head or as another alternative, using a hydraulically actuated perforating head 89. Once the detonating cord is initiated, it results in the development and propagation of a pressure pulse or wave within the pipe string 76. This pressure wave is then communicated through the fluid in the pipe 76 and casing 60 to the plug 19 at the inner end of the cylinders 12. If necessary, the pipe string 76 may be centered in the casing by means of conventional centralizers 78. Centering the pipe string 76 in the casing string may be important in view of the importance f propagating a pressure wave to the cylinders 12 on all sides so that the force of this pressure wave is sufficient to rupture membrane or disc 68 in the plug 19. This

rupture of disc 68 sequentially initiate the powders 72 and 74 within the shell 64 positioned in the plug 19. Tests have shown that initiation of the detonator will take place reliably without the provision of an air space 70 in the shell 64. The amount of pressure required to rupture the disc is increased when the air space is eliminated; however, detonation does take place. Satisfactorily, it is believed that the principle behind the detonation is an adiabatic compression within the shell 64 which is sufficient to initiate the primary charge 72. Therefore, it appears to only be necessary to generate sufficient pressure within the interior of the casing bore to cause the ruptured disc 68 to rupture which will thereby initiate the detonator in the shell 64. When a second charge is present in the piston 12, initiation of the detonator is communicated through the opening 48 within the carrier 46 to detonate the second charge 58. This detonation produces a back force that is directed onto the plug 19 in such a manner as to strip the threads 22 and push the plug 19 into the casing bore.

In the configuration shown in Figure 6, the smaller diameter pipe 76 housing the detonating cord, may be provided with slots or holes in the outside walls thereof to facilitate transmission of a pressure wave emanating from the detonating cord to the flowport cylinders 12. However, experiments have shown that a pressure wave may be propagated through the walls of solid pipe which is sufficient to initiate the detonators within the plug 19 on the cylinders 12. The system shown in Figure 6 with a production packer 86 set in place will permit the completion to take place with an under-balanced fluid in the pipe string, so that upon opening the flowport 12 to the casing and the formation F, fluids may be readily received into the casing string through the now open

cylinder 12 and from there into the production tubing 76 for conveyance to the surface.

It is contemplated that flowports can be opened by initiating a detonating cord of sufficient explosive strength to open a soft metal plug 19 either by an initial compressional wave or if the plug were designed to be stronger, the detonating cord can be used to initiate a detonator charge which itself would remove or open the plug 19 or which would in turn initiate a secondary charge 58 to likewise remove or open the plug 19.

One of the benefits of the system described herein is in the opening of a flowport in this manner utilizes the formation pressure to create an explosive decompression across the face of the formation rock in front of the flowport which helps to remove skin damage from the formation caused by drilling fluids. This in turn will increase permeability of the formation near the borehole. This technique also utilizes the differential pressure due to an under balanced pressure condition and the rebounding shock wave in the opposite direction (rarefaction) to blow the flowport cover, plug, etc., into the interior of the casing pipe. Explosively opening the flowport allows all flowports or a selected group of flowports to be opened after the production tubing is run into the well (Figure 6) to provide a safe well during completion and greatly reducing the chances of a blowout. Such underbalanced completion prevents loss of drilling/completion fluids into the formation. Also eliminated are the need for perforating guns and cased hold drill stem testers. These casings conveyed flowports thus provide steel lined openings between the interior of the pipe and the reservoir rock (formation) to be opened up without firing explosive charges through the wall of the pipe itself and the surrounding cement. Flowports

eliminate the cost of the charges, the time to install them, the damage to the pipe, and the reduced permeability and damage to the rock, exposed by the perforation, due to glazing and vaporized material being forced into the rock.

After blowports are opened, a perfectly round steel lined opening is provided between the interior of the casing and the formation, with a beveled edge towards the interior of the pipe. This round beveled opening will facilitate the application of perf balls or ball sealers. During a hydraulic stimulation or frac job, these hard rubber perf balls are dropped into the well when the formation breaks down or begins to fracture in front of a port such that the amount of fluid going into a particular port increases. Increased flow into a perforation or port will cause a perf ball to be sucked into it sealing it off causing the pressure to rise until another port is forced to take flow. This technique prevents the ports positioned in front of high permeability reservoir rock that least need the treatment fluid from having all the treatment fluid and forces the ports requiring treatment and/or fracturing to take fluid.

The significant difference between the flowports of this invention and wireline or tubing conveyed perforations is that a perfectly round (as described by the inner end 27 of piston 12), steel lined, beveled hole is provided between the interior of the pipe and the formation. Such a uniform opening is preferred and much more suited for hydraulic treatment and fracturing because wireline and tubing conveyed perforating leaves jagged varying size holes that are hard to seal with perf balls. Also, a round, beveled, uniform sized hole created by casing conveyed flowports allows proper sizing of perf balls which prevents them from becoming stuck as they often do in irregular holes created by wireline and tubing

conveyed perforating. Flowports as used herein explosively decompress the reservoir rock in front of them when opened in under balanced conditions, thus helping to remove skin damage and improve permeability. Flowports do not glaze the hole or reduce reservoir rock permeability with molten or vaporized material as do explosive perforations using shaped charges.

Casing conveyed flowports are opened following the shock wave created by the detonation of an explosive in the interior of the pipe, in this case detonating cord, in the casing to initiate individual detonators in the flowport covers causing the covers to be blown into the interior of the pipe.

It is readily appreciated that various other techniques could be developed for providing the placement of a detonating cord into the interior of either a casing pipe string or a production string in order to initiate the pressure wave described herein for detonating the perforation devices. For example, the detonating cord could be pumped in behind a pumpable plug or the like to position the detonating cord into a horizontal reach of pipe. In a vertical or nearly vertical pipe section, gravity would be sufficient to lower a detonating cord weighted on its lower end, into a pipe string. In addition, other methods could be used to develop a pressure wave for initiating the shaped charge. Also, it is readily seen that a variety of detonators might be used to open the cylinder 12 or to initiate the explosion of a secondary charge within the centralizing cylinder 12 to open the cylinder. Therefore, while particular embodiments of the present invention have been shown and described, it is apparent that changes and modifications may be made without departing from this invention as defined by the appended claims.

Claims

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1. A completion system for use in a borehole drilled into earth formations wherein it is desirable to establish a fluid communication path between the interior of a casing pipe string and an earth formation traversed by a borehole, comprising:

a pipe string in the borehole, said pipe string having flowports mounted in the wall of said pipe string and arranged to provide fluid flowpaths between the interior of the pipe string and earth formations exposed along the borehole wall;

means for blocking the flowpaths to prevent fluid flow between the interior of the pipe string and the formations;

explosive means for removing said blocking means; and

activation means comprised of a pressure wave producing device which when operated produces a pressure pulse which activates said explosive means.

2. A completion system for use in a borehole drilled into earth formations wherein it is desirable to establish a fluid communication path between interior of a pipe string in the borehole and an earth formation traversed by the borehole, comprising:

a pipe string for placement in the borehole;

flowport means arranged in the wall of said pipe string to provide fluid flowpaths between the pipe string and an earth formation;

explosive means carried by said pipe string into the borehole for unblocking said flowport means to allow fluid communication between the pipe string and the earth formation upon activation of said explosive means;

activation means comprised of a selectively operable

pressure wave producing device positioned within said pipe string and spaced from said explosive means, which pressure wave producing device, when operated, produces a pressure pulse which activates said explosive means; and

means for operating said activation means.

3. The completion system of claim 1 or 2, wherein said activation means is arranged to be separately conveyed into said pipe string to a position adjacent said fluid flowpaths after said pipe string is positioned in the borehole.

4. The completion system of claim 1, 2 or 3, wherein said explosive means includes an explosive charge which is oriented to direct a major portion of its explosive force into unblocking the flowpath.

5. The completion system of any preceding claim, wherein said activation means is a detonating cord which is positioned longitudinally within the interior of said pipe string.

6. The completion system of claim 5, wherein said detonating cord is conveyed within a smaller pipe string which is positioned within said casing pipe string.

7. The completion system of claim 6, wherein said smaller pipe string houses the detonating cord and wherein said smaller pipe string has openings in its outer wall to facilitate travel of a pressure wave emanating from said detonating cord through said openings into contact with explosive means carried in said casing pipe string, when said detonating cord is operated.

8. The completion system of any preceding claim, wherein said flowpath is provided by selectively extendible pistons mounted in the wall of said pipe string and further wherein said activation means is a detonating cord arranged to be operated when it is out of direct contact with said pistons when extended for providing a pressure wave upon orientation thereof to activate said explosive means.

9. A method of perforating an earth formation traversed by a borehole to provide a fluid communication path between a borehole casing pipe string and the earth formation, comprising the steps of:

positioning explosive charges on the casing pipe string at the surface for insertion into the borehole on the casing pipe string;

positioning the casing pipe string in the borehole where formations are to be completed;

moving normally closed flowports arranged in the wall of said casing pipe string to an extended position between the casing pipe string and the earth formation to provide a flowpath therebetween;

positioning an explosive detonating device in the casing pipe string; and

activating the explosive detonating device to produce a pressure wave within the casing pipe string to detonate the explosive charges on the casing pipe string to open said the flowports.

10. A method of providing a fluid communication path between a pipe string in a borehole and an earth formation traversed by the borehole, comprising the steps of:

running flowports into the borehole on the pipe string which flowports are normally blocked by selectively removable means;

running explosive charges into the borehole on the

pipe string adjacent the flowports, said explosive charges being operable to open said flowports;

positioning an elongated explosive detonating device in the pipe string; and

activating the detonating device to produce a pressure wave within the pipe string to detonate the explosive charges on the pipe string to open said flowports.

11. The method of claims 9 or 10, further comprising after positioning the pipe string with explosive charges in the borehole where formations are to be completed and prior to detonating the explosive charges, injecting cement through the pipe string into a space between said pipe string and the formation.

12. The method of claims 9 or 10, wherein said explosive charges are positioned within pistons, which pistons are movably mounted within the side walls of portions of the pipe string, said method further comprising moving the pistons from a retracted position substantially within the profile of the outside diameter of the pipe string to an extended position wherein one end of the pistons is extended toward contact with the earth formations.

13. The method of claim 12, wherein said pistons are moved to an outwardly extended position by moving a deploying device through the inside of the pipe string into contact with an inner end of the retracted pistons to slidably move the pistons through the wall of the pipe to an outwardly extended position, said method further comprising latching the piston in the outwardly extended position.

14. A method of completing a borehole drilled into earth formations wherein it is desirable to provide a fluid communication path between an earth formation and a pipe

string, comprising:

positioning normally closed flowports in the wall of a pipe string, said flowports having explosive devices positioned therein, said explosive devices being arranged for detonation in response to a pressure pulse to open the normally closed flowports;

separately positioning a pressure wave producing device in the borehole in proximity to the flowports but physically spaced therefrom; and

operating the pressure wave producing device to generate a pressure pulse to initiate detonation of the explosive devices.

15. The method of claim 14, wherein the explosive devices are housed in pistons transversely mounted within the wall of the pipe for movement between retracted and extended positions, said method further comprising applying a force to an inner end of the piston within the pipe to move an outer end of such pistons toward contact with the earth formations to be completed and fixing the pistons in an extended position to centralize the pipe in the borehole.

16. The method of claim 15, further comprising prior to detonating the explosive devices, injecting cement through the pipe into a space between the formations and the pipe, and allowing the cement to set.

17. The method of claim 15, wherein the force for extending the pistons into contact with the formations is provided by moving a plunger through the pipe to physically contact the inner end of the pistons and thereby to push the outer ends of the pistons toward contact with the earth formation.

18. A method of opening a fluid communication path between a pipe string in a borehole and an earth

formation traversed by the borehole, comprising the steps of:

positioning a plurality of normally closed flowpaths within the wall of a pipe string;

positioning detonation charges within the flowpaths which when operated will open the normally closed flowpath;

positioning the pipe string in the borehole with the flowpaths and charges aligned with a selected formation; and

after running the detonation charges and flowpaths into the borehole on the pipe string, in a separate operation generating a pressure wave in the pipe string to operate the detonation charges.

19. A method of completing a borehole traversing earth formations, comprising the steps of:

installing normally closed flowports in the wall of casing pipe string;

installing detonating devices in the flowports;

setting the casing pipe string in the borehole;

running production tubing into the casing pipe string, the interior bore of said production tubing being at pressure below the formation pressure; and

activating said detonating devices by generating a pressure wave in said production tubing to open said flowports in the casing pipe to said formation.

20. The method of claim 24, further comprising packing off an annular space between the production tubing and the casing pipe above the detonating devices.

21. A completion system for use in a borehole drilled in earth formations, substantially as hereinbefore described with reference to the accompanying drawings.

22. A method of perforating an earth formation traversed by a borehole, substantially as hereinbefore described with reference to the accompanying drawings.

23. A method of providing a fluid communication path between a pipe string in a borehole and an earth formation, substantially as hereinbefore described with reference to the accompanying drawings.

24. A method of completing a borehole, substantially as hereinbefore described with reference to the accompanying drawings.